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Design and Experimental Validation of Acoustic Metamaterial Slab

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Abstract

A topology optimization [1] based approach for designing 2D acoustic metamaterial slaps exhibiting negative refraction [2] is detailed along with a procedure for, and the results of, an experimental investigation of one such slab [3]. The presence of experimentally observed attenuation of the pressure field is discussed and the importance of the attenuation for the design of practically applicable acoustic metamaterials considered.

A 2D spatial model domain is considered in the design approach. The acoustics is modeled in the frequency domain using the Helmholtz equation and approximate far field boundary conditions are considered at the truncated boundary of the domain. A finite slab of designable material, composed of an array of identical unit cells, is situated in the model domain in an air background. The material distribution in the unit cell is controlled by a mathematical design field which in turn is discretized into a grid of piecewise constant design variables. The slab is exited by a modulated plane wave, driven at a chosen frequency, incident on the slab at a prescribed angle. The design problem is formulated as an optimization problem with the goal of minimizing the amplitude difference between the solution to the model problem for a given design and a prescribed modulated plane wave behind the slab, through the modification of the material distribution in the identical unit cells. The position of the prescribed plane wave is chosen to obtain a desired effective refractive index of the slab. The Globally Convergent Method of Moving Asymptotes [4] is used to solve the optimization problem.

The experimental investigation was performed in a pseudo 2D approximately exterior acoustic environment. The experimental setup consisted of an acoustic cavity with absorbing foam walls in the (x,y)-plane and hard plastic walls out of plane. An array of micro loudspeakers were used to approximate the modulated plane wave exciting the slab. A 20 x 9 unit cell metamaterial slab, 3D-printed in ABS plastic, was placed at the center of the cavity in a freely rotatable disc. The pressure field in and around the slab was recorded by scanning a microphone flush mounted in the ceiling plate for different orientations of the slab.

References

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